

## **COST EFFECTIVE METHOD FOR MANUFACTURING MICRO GAS TURBINE COMPONENTS**

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### **SUMMARY**

A 10 kW Micro Gas Turbine (MGT) is under development at the Propulsion Division, National Aerospace Laboratories, Bangalore for stationary power applications. The cost of the MGT unit depends on the manufacturing cost of the individual components and the number of units produced. There is a need to optimize the manufacturing processes to reduce the cost of production. The method of manufacturing the components through Rapid Prototyping (RPT) followed by investment casting was found to be cost effective and brought down the total cost of the unit considerably. This paper describes, in detail the manufacturing processes adopted for producing one of the MGT components, namely the compressor stage consisting of impeller and diffuser. A comparison of the dimensional accuracies, surface finish and typical cost involved in manufacturing the compressor component by conventional CNC milling machine and by casting through the RPT route is presented in this paper.

**KEY WORDS:** *Gas turbine, Compressor, Turbine, Rapid prototyping, CNC milling, Vacuum investment casting*

### **1. INTRODUCTION**

A Micro Gas-turbine (MGT) is a power generating device. The advantages of the MGT over existing diesel engine generator sets are that it is smaller in size and in weight and has multi-fuel capability, lower emissions, lower noise, vibration-free operation and maintenance. It comprises of a compressor, combustor, turbine, alternator and recuperator. The cost of the MGT unit depends on the manufacturing cost of the individual critical components and the number of units produced. Among these components, the rotating and stationary components like the compressor and diffuser ring shapes are very complex and require special machines to manufacture them. Due to the complex shape, the 5-axis CNC machines are normally used to manufacture these components. Advanced technology like investment casting using the wax model generated from RPT will be a better option to manufacture these components with reduction in cost and produce in large scale.

Ashgriz, et al [1] investigated and suggested the optimal injection parameters during pattern making in order to obtain good dimensional accuracy of wax patterns. Beeley, et al [2] described the importance of manufacturing aircraft components and armaments using investment casting. Jacobs [3] highlighted the reproducibility of castings within close tolerances and cost saving over the parts produced by CNC milling. Zhang et al and Minev et al [4, 5] evaluated the quality of the RPT models used in the manufacture of wax patterns for investment casting based on geometrical

accuracy, surface finish, visual inspection of RPT patterns and casting quality based on X-ray analysis.

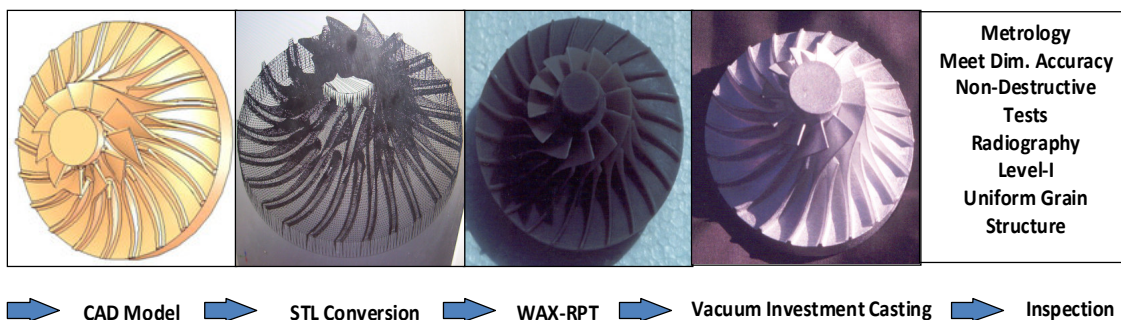
A typical component of an MGT namely, a compressor stage consisting of impeller and vane diffuser ring was manufactured using a 5-axis CNC milling and investment casting. The components manufactured by both the methods were checked for dimensional accuracies, surface finish and porosity. A comparison was made to evaluate the total cost and the time involved to manufacture the components by both the methods.

This paper describes in detail the procedure adopted for manufacturing the components by CNC machining as well as investment casting. The detailed modeling procedure, tolerances required to allow for shrinkages, inspection techniques adopted are described in detail.

## 2. PROCEDURE ADOPTED FOR CASTING PROCESS

The investment casting process is the best technology to manufacture micro components for mass production. The sequences of process involved to manufacture a typical MGT compressor as shown in Figure-1. There are basically five steps involved to produce the components through investment casting. These five steps are

- Step-I CAD model generation using SOLIDWORKS from the design data and saving the CAD model in STL format.
- Step-II Generation of a wax model of the design component from the STL file using a thermo jet 3-D printer.
- Step-III Preparation of a ceramic shell on the wax model, de-waxing and sintering to get the ceramic mould.
- Step-IV Pouring the metal into the ceramic mould and cleaning the mould to get the cast components.
- Step-V Quality assurance tests for dimensional accuracies and non-destructive tests (NDT) for checking blow holes and cracks.



**Figure-1 Vacuum investment casting process layout**

## 3. MODELING, GEOMETRY AND MATERIALS

3D-CAD models of the impeller and the diffuser and its detailed geometry are shown in Figure-2. The left side of the figure shows the impeller wheel and the right side of the figure shows the vane diffuser ring. The basic geometry and co-ordinates of the compressor blades and diffuser were generated using an in-house computer code. The co-ordinates thus generated are used in modeling software SOLIDWORKS for generation of the compressor and diffuser models for MGT. The RPT machine namely, 3D Thermo jet, requires the model to be generated in a number of horizontal

layers, which are called slices. Each slice is a mesh of triangular elements approximating to the original shape. This is recommended in order to reproduce the shape accurately. For this, the tolerances on the volumetric deviation should be less than  $7\mu\text{m}$  for a slice thickness of  $7\mu\text{m}$  and the resolution angle should be greater than 10 degrees. To achieve these values of tolerance for the model of the compressor considered, the model turns out to have 1.85 lakhs of triangular elements and for the diffuser, there are about one lakh of triangular elements.

To account for shrinkage during the wax model and the ceramic shell preparation, the original dimensions of the model need to be scaled to 1.96% (consisting of 1.76% for wax model and 0.2% for ceramic shell shrinkages). This value is derived based on practical experience and after many trials. High quality imported Aluminum alloy (Al6070-T6) material was used to cast and machine the compressor.

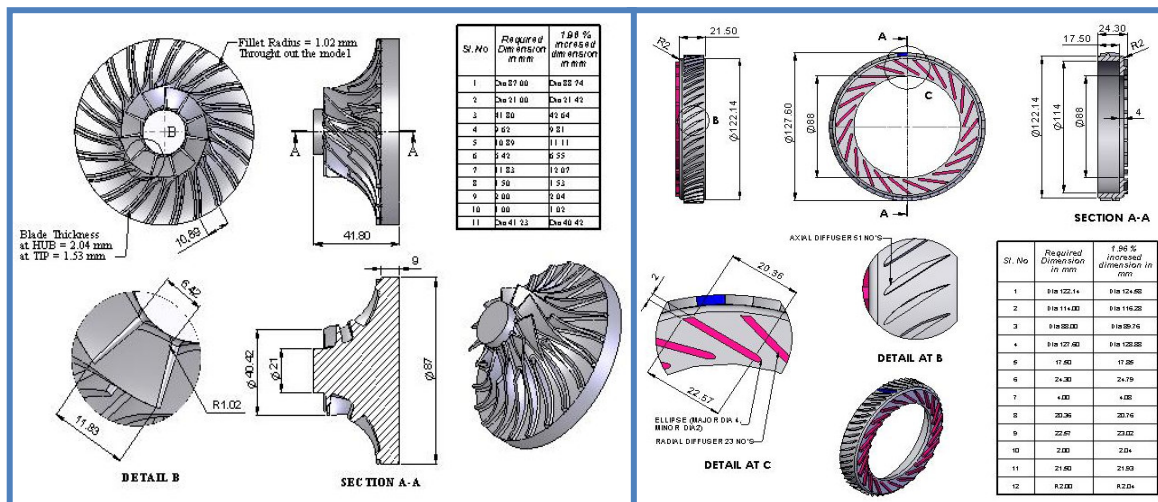


Figure – 2, 3D Models of MGT compressor and diffuser

#### 4. RPT WAX MODEL

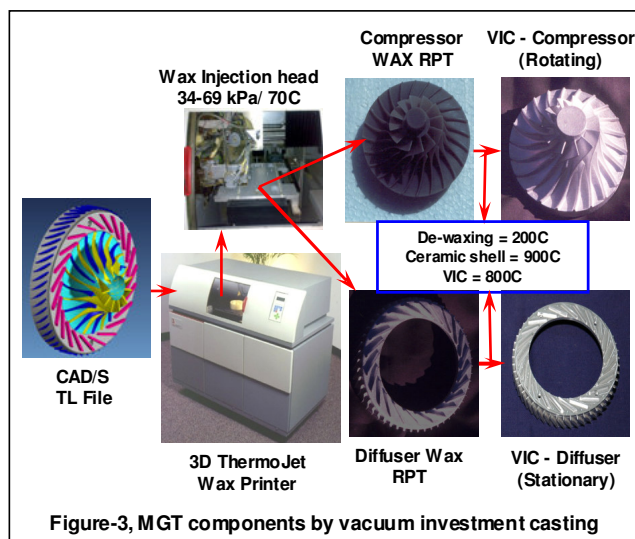
The layer based sliced data in STL format was used as an input to the 3-D Thermo jet machine to produce wax models. The optimized machine parameters namely wax injection pressure of 34-69 kilo Pascal and the wax temperature of 70C was selected. The wax drying time for each layer of deposition was also set to 6-8 minutes. The above mentioned parameters depend on the wax material, surface finish and shrinkage. The trade name for the wax material used namely polyurethane wax is Gold STAR WAX

120-Royal. With the above set parameters, the wax model produced had a very good surface structure. The wax model was scanned using a 3D laser scanner to get clouds of surface points at various locations. Using these surface points, the 3D model was regenerated using the CAD software CATIA. The generated 3D model was superimposed on the original CAD model and the dimensions were checked. It was observed that the desired values of the dimensions are within the allowable limits. The generated wax model was soldered with additional wax pieces, namely, wax runner and standard wax cup, for the purposes of pouring metal and allowing air bubbles to escape.

#### 5. CERAMIC SHELL AND CASTING

The required ceramic slurry, namely, colloidal silica (primary coat) and mullite (secondary coat) was prepared and sufficient thickness (around six coats) of this slurry was deposited on the wax model. The wet pattern was dried for one to two days in a controlled atmosphere. The ceramic mould was then de-waxed using steam at 7 bar for a duration of 12 minutes in the autoclave

furnace. Then the mould was heated (sintered) in two stages, first to 750C and then to 900C for a period of 15-45 minutes to avoid the cracking of the mould. Any ash or ceramic particles left inside the mould was removed by shaking the mould. Prior to pouring of metal into the mould, they are preheated to 400-500C to remove the moisture content present in the mould. The required aluminum alloy was melted to 700-800C and poured into the mould under a vacuum environment to create the required component. The mould was taken out and the ceramic shell covering the part was broken and cleaned to get the required component. The casting component was subjected to radiography test to check for pin holes and cracks. Tests showed that the component had conformed to Grade-AI quality. Then the component was inspected in a 3axis co-ordinate measuring machine (CMM) to get the profile geometry and overall dimensions. The profile was found to match with the designed profile within the accuracy level required (100Microns). The deviations in the overall dimensions are within the limits of  $\pm 350\mu\text{m}$ . The generalized scheme for casting process is shown in Figure-3. Some of the observations made during casting process are given in Table-I.



**Table-I Cast trial results/observations**

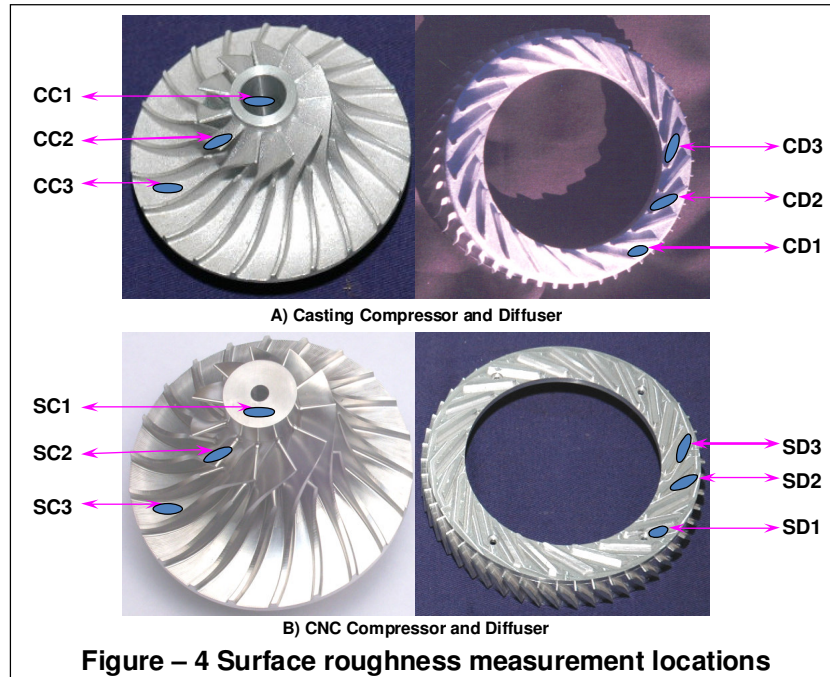
Process stage	Result/Observations
Autoclave/	Produced good moulds, no cracks found
Firing/Sintering	No deposit found in mould
Shake-out	No loose deposit found in the interior
Casting	Good castings produced
Penetrant Test (PT)	Passed by penetrant flaw detection, No surface defects found
X-ray analysis	Passed*

\* Porosity level(AI) : ASTM-E-446/E-186 for heavy walled castings

## 6. CNC MACHINING

The 5-axis CNC machining process was adopted for complex shaped objects like the components considered here. In this machining process a good surface finish as well as close dimensional accuracies could be obtained. The required data in terms of surface coordinates were generated from the design program. These surface data along with the hub and shroud co-ordinates were used as an input to the CNC preprocessor. The preprocessor generates the model using these data and optimizes the cutter size and cutter path. The required blank is first prepared from the CNC turning lathe from the shroud co-ordinates and the overall geometry. This blank was mounted on the 5axis CNC milling machine and the two successive impeller channels were machined from the preprocessed data to create a test piece. These two channels include the main blade and splitter blade. These two channels were inspected using a co-ordinate measuring machine (CMM) and compared with the design data for acceptance. Once the test piece is approved all the channels of the impeller were milled in a new blank. The machined impeller is again inspected using CMM machine to get the surface coordinates and overall geometry. The inspection data showed that the overall dimensions are within  $5\mu\text{m}$ , whereas the blade surfaces are within  $10\text{-}30\mu\text{m}$ . Similar procedure was adopted for milling the diffuser ring. The CNC milled impeller and diffuser are shown in Figure-4.





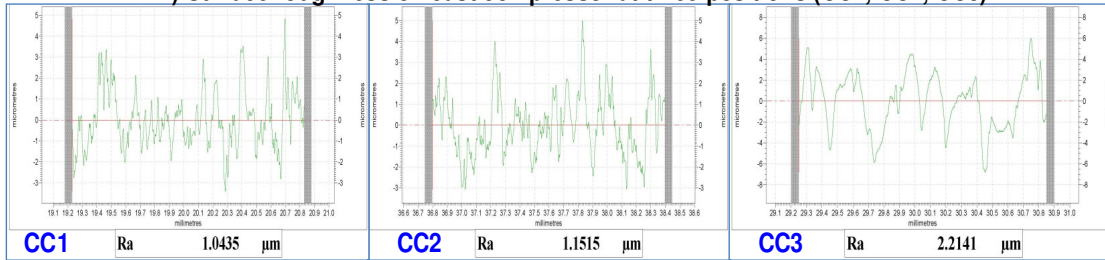
## 7. QUALITY VALIDATION OF CASTINGS AND CNC MILLED COMPONENTS

The structural strength and life of the product depends on the surface texture. To assess whether the surface quality of the RPT models had a noticeable influence on the quality of the final castings produced, they were examined for surface roughness. The measurements were taken on both castings and CNC milled part of the components at three locations using a Thomson Hobson machine (Ultra Surface Contour Tester). These locations are shown in Figure-4. The results of surface roughness are shown in Figure-5 for various locations. The quality standard based on the root mean square value of the surface roughness is given in Table-II. In Figure-5, the surface roughness in  $\mu\text{m}$  is plotted against a known surface distance of about 3mm. The root mean square (rms) values obtained from the surface roughness variation will give indicative values of surface roughness for comparison purposes.

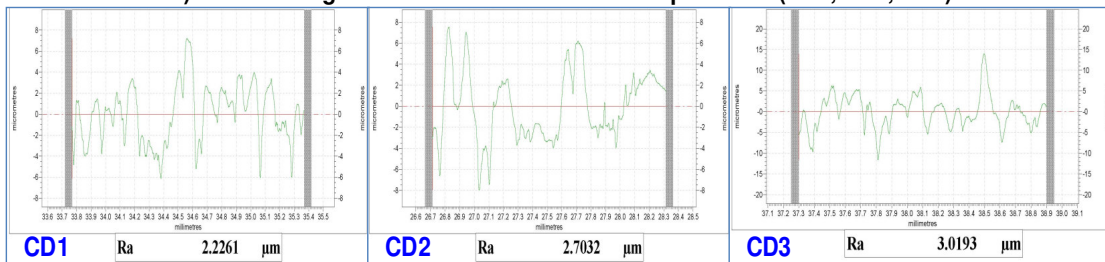
In the majority of cases, the surface roughness was greatest at location 3, though the value of surface roughness is within the limits mentioned in the standards. The surface roughness value within the channel on the hub and blade surface is slightly higher than the values at locations 1 and 2. Both components produced by RPT/casting and CNC milling have good surface finish. It is observed that casting can produce components of same quality as that of CNC milled.

It is observed that the surface roughness of each component produced through casting has different roughness values whereas the same surface roughness could be obtained through CNC milling. To get repeatability in the surface roughness of the castings, they need to be treated with a process like sand blasting.

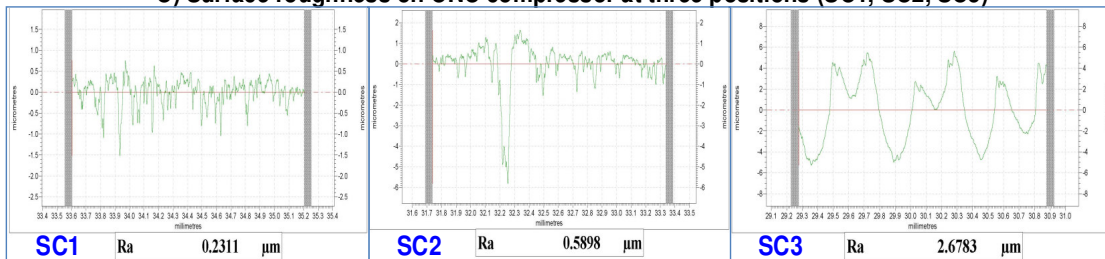
**A) Surface roughness on cast compressor at three positions (CC1, CC2, CC3)**



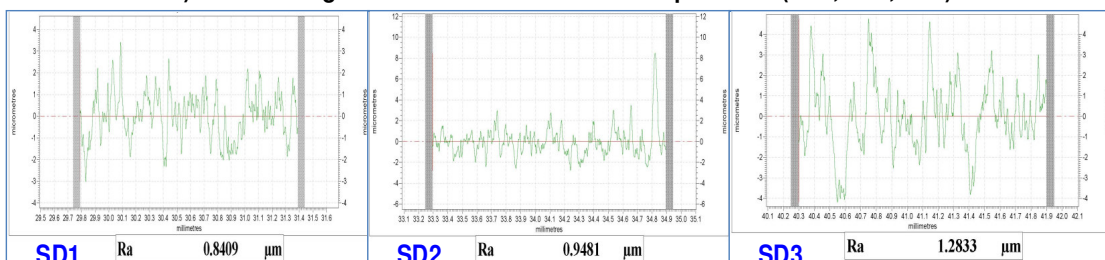
**B) Surface roughness on cast diffuser at three positions (CD1, CD2, CD3)**



**C) Surface roughness on CNC compressor at three positions (SC1, SC2, SC3)**



**D) Surface roughness on CNC diffuser at three positions (SD1, SD2, SD3)**



**Figure-5, Surface roughness graphical representation**

**Table – II Surface roughness measurements and standards**

<b>CASTINGS (Ra in <math>\mu\text{m}</math>)</b>	<b>5-AXIS CNC MILLING (Ra in <math>\mu\text{m}</math>)</b>
<b>A) Compressor (CC)</b> CC1 = 1.0435 CC2 = 1.1515 CC3 = 2.2141	<b>C) Compressor (SC)</b> SC1 = 0.2311 SC2 = 0.5898 SC3 = 2.6783
<b>B) Diffuser (CD)</b> CD1 = 2.2261 CD2 = 2.7032 CD3 = 3.0193	<b>D) Diffuser (SD)</b> SD1 = 0.8409 SD2 = 0.9481 SD3 = 1.2833
Up to 0.8 $\mu\text{m}$ Bearing surface (N6), Up to 1.6 $\mu\text{m}$ Static mating surface (N7) and Up to 3.2 $\mu\text{m}$ Smooth machined surface (N8) the grades which was produced by Castings and machined components is accepted for micro system like MGT as per BS 1134 / ISO 1302 standards	

## 8. COST AND PRODUCTION TIME

The approximate cost involved for fabricating a MGT micro component like the rotating compressor and stationary diffuser by vacuum investment casting and CNC milling is tabulated in Table-III. This table shows that the cost and time involved for a minimum quantity of one number per each component. It is observed that the cost production using a casting process is nearly two orders lower than CNC milling and the time of production is around half that of CNC machining. If the number of quantities in production is increased, Casting/RPT route has a great advantage.

**TABLE-III Comparison of Cost and Time**

<b>CASTING</b>		<b>MACHINING</b>	
<b>Process steps</b>	<b>Rupees/Model/Time</b>	<b>Rupees/Model/Time</b>	<b>Process steps</b>
CAD Modeling	Rs 2000/5H	Rs 2000/5H	CAD Modeling
Wax Patterning	Rs 1000/2-4D	Rs 20,000/2W	Special Programming
Ceramic Shell Preparation	Rs 1000/1-2D	Rs 40,000/1-5D	Rough Turning and Milling
VIC	Rs 2000/3-5H	Rs 1,00,000/1-2W	Final Milling
Polishing/Shot blasting	Rs 500/2H	--	--
Inspection/Quality	Rs 5000/1-5D	Rs 38,000/1-5D	Inspection/Quality
<b>Total Cost/ Total Time</b>	<b>Rs 12,000/2W</b>	<b>Rs.2,00,000/5.5W</b>	<b>Total Cost/ Total Time</b>

Where H, D and W are denoted by Hours, Days and Weeks

## 9. CONCLUSIONS

A typical MGT component manufactured using CNC milling and casting has been compared in terms of accuracy, cost and time. The RPT followed by casting provides accuracies as comparable

to CNC milling. The cost of production is nearly two orders lower than CNC milling. With a few initial trials it is possible to get components with RPT/casting in comparable with a CNC milling machine and the production rate can be increased to meet the market demand.

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